CARBON FIBRE REINFORCED CONCRETE AS A SMART MATERIAL CAPABLE OF NON-DESTRUCTIVE FLAW DETECTION

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ABSTRACT

Concrete is the most widely used in construction material. It is the material of choice where strength, performance, durability, fire resistance and abrasion resistance are required. Electrically conducting concrete, as provided by the addition of short carbon fibres (0.2-0.4 vol. %) to concrete, can function as a smart structure material that allows non-destructive electrical probing for the monitoring of flaws. The electrical signal is related to an increase in the concrete's volume resistivity during crack generation or propagation and a decrease in the resistivity during crack closure. The linearity between the volume resistivity change and the compressive stress was good for mortar containing carbon fibres together with either methylcellulose or latex as dispersants. However, the linearity was poor for mortar containing carbon fibres together with both methylcellulose and silica fume, as this mortar required a minimum compressive stress for crack closure, whereas the other two mortars did not. When the compressive stress was increased in the first cycle up to the fracture stress, the volume resistivity Increased by 1040% for the mortar containing carbon fibres and methylcellulose, but only 385% for that containing fibres and latex. In contrast, mortars without carbon fibres showed no variation of the resistivity upon compression up to fracture.

1. Introduction

The use of fibres in concrete to improve pre- and post-cracking behaviour has gained popularity. Since 1967, several different fibre types and materials have been used in concrete to improve its physical properties and durability. This is supported by large number of independent research results showing the ability of fibres to improve durability and physical properties of concrete Smart concrete structures that provide the capability of non-destructive flaw detection allow concrete structures to be repaired before it is too late. This capability is critically needed for highways, bridges and nuclear power plants.

Fibre Reinforced Concrete (FRC) is cement concrete reinforced mixture with randomly distributed discrete fibres. In the FRC, a number of small fibres are dispersed and distributed randomly in the concrete at the time of mixing, and thus improve concrete properties in all directions. It has been used in construction with its higher flexural, tensile strength, resistance to splitting, impact resistance and excellent permeability and frost resistance.

The new technology of using carbon fibres made the invention of carbon fibre reinforced concrete to overcome the problems associated with cement-based materials such as low tensile strength, poor fracture toughness of cementitious composites. Cracks and weak in tension are the limitations of conventional concrete.

Thus, recent years have shown the extensive use of fibres like glass, steel, carbon etc. in order to face the challenges of the growing civil engineering industry. Addition of such carbon fibres increases fire resistance, impact, compressive, erosion, split tensile and flexural strength, durability, fracture and shrinkage characteristics of cracks. Objective of this work is to present the information accumulated from various researches and to show the benefit out of using carbon fibres. No works on intrinsically smart concrete have been previously published except for a 1992 news article (ENG June 22 pp 14-15) on 'self-test concrete' involving glass and carbon fibres and developed by H Yanagida of the University of Tokyo. Most prior work relates to concrete rendered smart extrinsically by the use of embedded sensors or an embedded chemical. The embedded chemical (calcium nitrite contained in polypropylene fibres) is for anticorrosion of steel reinforcement bars; the technology was developed by C Dry of University of Illinois, Urbana, and disclosed in another 1992 news article (Stuat T 1992 R & D magazine pp 74-8).

Carbon fibres have low density, high thermal conductivity, good chemical stability and excellent abrasion resistance, and it can be used to reduce cracking and shrinkage. These fibres increase structural properties such as tensile and flexural strengths, flexural toughness and impact resistance. Carbon fibres also increase durability and dry shrinkage. However, the addition of carbon fibres decreases the electrical resistance [1,2,3].

Fibres with different volume fractions have been used to study the effect of carbon fibres on mechanical properties (compressive strength, splitting tensile strength and flexural strength) of concrete. Carbon fibre, is a material consisting of fibres about 5–10 μm in diameter and composed mostly of carbon atoms. To produce carbon fibre, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fibre as the crystal shape gives the fibre high strength-to-volume ratio (making it strong for its size) [6,7,8].

The properties of carbon fibres, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared to similar fibres, such as glass fibres or plastic fibres [6, 9].

2. Methodology tests

2.1 Raw Materials

2.1.1. Carbon fibre

Carbon fibres (alternatively CF, graphite fibre) are fibres about 5–10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibres have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fibre very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibres, such as glass fibres or plastic fibres.

2.1.2 Methyl cellulose

Methyl cellulose is a chemical compound derived from cellulose. It is a hydrophilic white powder in pure form and dissolves in cold (but not in hot) water, forming a clear viscous solution or gel. It is sold under a variety of trade names and is used as a thickener and emulsifier in various food and cosmetic products, and also as a treatment of constipation. Like cellulose, it is not digestible, not toxic, and not an allergen.

Methyl cellulose does not occur naturally and is synthetically produced by heating cellulose with caustic solution (e.g. a solution of sodium hydroxide) and treating it with methyl chloride. In the substitution reaction that follows, the hydroxyl residues (-OH functional groups) are replaced by methane oxide (-OCH_3 groups).

2.1.3 Silica fumes

Silica fume, also known as micro silica, (CAS number 69012-64-2, and EINECS number 273-761-1) is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

It is sometimes confused with fumed silica (also known as pyrogenic silica, CAS number 112945-52-5). However, the production process, particle characteristics and fields of application of fumed silica are all different from those of silica fume.

2.2 Mixing procedure

1. Firstly coarse aggregates and silica fumes were added together into the mixer.
2. While mixing 50 % of water was added.
3. Mixer was allowed to rotate for 1.5 min and sand was slowly added into the mixer.
4. Cement was mixed thereafter
5. Simultaneously Methylcellulose was being dissolved in hot water for 5 min and then poured into mixer.
6. Remaining water was poured and carbon fibres were added and mixed for 5 min.

7. A break of 1.5 min then left to rotate for another 2 mins.
8. Mixture was poured into oiled moulds and hand tamping was done.
9. De-mould after 1 day and put into water for 28 days.

2.3 Curing procedure

Curing plays an important role on strength development and durability of concrete. Curing takes place immediately after concrete placing and finishing, and involves maintenance of desired moisture and temperature conditions, both at depth and near the surface, for extended periods of time. Properly cured concrete has an adequate amount of moisture for continued hydration and development of strength, volume stability, resistance to freezing and thawing, and abrasion and scaling resistance.

The length of adequate curing time is dependent on the following factors:

1.Mixture proportions
2.Specified strength
3.Size and shape of concrete member
4.Ambient weather conditions
5.Future exposure conditions

2.4 Testing process

Procedure: Compressive Strength Test of Concrete Cubes

For testing cubes of 15cm X 15cm X 15cm depending upon the size of aggregate are used.

This concrete is poured in the mould and tampered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of these specimens should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen. These specimens are tested by compression testing machine after 28 days curing. Load should be applied gradually at the rate of 140 kg/cm^2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

Following are the procedure for testing Compressive strength of Concrete Cubes

Apparatus for Concrete Cube Test

Compression testing machine

Preparation of Concrete Cube Specimen

The proportion and material for making these test specimens are from the same concrete used in the field.

Specimen

4 cubes of 15 cm size Mix. M20

Mixing of Concrete for Cube Test

Mix the concrete either by hand or in a laboratory batch mixer

RESUTS AND DISCUSSION

In 150 mm cube with nails at a gap of 9cm (using hammer drill) having wires wounded along stress axis is better than nails in perpendicular to stress axis.

It essentially means that it is quite possible to predict the stress values in the field using the carbon fibre, silica fume and methyl cellulose combination.

It is also seen that once the stress v/s strain and resistance v/s strain

(R-Ro/Ro where Ro is the initial resistance) graphs are drawn using a cube compression test, Field experiments can be conducted to get actual stress values.

Thus, health monitoring of structures can be carried out using this simple procedure. Carbon fibre, methyl cellulose and silica fume. Carbon fibre methyl cellulose and silica fume (150x150x150).

CONCLUSION

The experimental results of compression test showed that the conductivity of the materials is significantly improved and that CFRC can be used for strain measurement and damage detection with fibre content of 0.15 vol. %. 0.2 vol. %. 0.5 vol. %. This is between the amounts (0.5 vol. %) used in previous literature.

According to compression tests, the similarity between the fractional change in electrical resistance and compressive strain indicates that the CFRC can be used as a self-sensing material for strain measurement within the proportional limit. The slope of fractional change with compressive strain is a good indicator for damage detection under compressive loading.

The strain gauges and the CFRC could both measure the strain on the compression side of a reinforced concrete portal frame, but the CFRC was more sensitive than the strain gauge. The strain gauges almost could not measure the strain on the tension side, but the CFRC had good accuracy and a higher sensitivity. The self-sensing of tensile strain and compressive strain and damage detection were more effective in the CFRC under different loadings. Therefore, the self-sensing ability of CFRC, as shown by the sensing of strain and damage detection, has been demonstrated.

In summary, the capability of low carbon fibre content CFRC (0.2 vol. % fibre content) for strain measurement and damage detection was confirmed, and the practical application of CFRC for strain measurement of a RC cube was demonstrated in this paper.

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